§18. Behavior of Toroidal Current and Other Plasma Parameters in Termination of Discharges in LHD

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In principle, heliotron devices do not need the toroidal current to confine plasma. However, it is predicted that finite toroidal current flows like bootstrap current in a heliotron reactor. When scenarios of the termination of discharges are considered in heliotron reactors, it is important to estimate how large power is released, and/or how large one turn voltage appears because they affect the design of the heat removal and the stability of the super conductor. In heliotron devices, magnetic surfaces still exists even while current decays, whose situation is quite different from that of tokamaks. Then comparative analysis of the current decay phase between heliotron and tokamaks might lead to the effect of existence of magnetic surfaces on the current decay phenomena. In order to study the above issues, it is important to know the typical behavior of the current and other plasma parameters in termination of discharges in LHD.

Figure 1 is the typical waveform of the toroidal current, electron density, electron temperature, bolometer signal, the emission signals from O(V) and C(III). Here, at t=3.3s, heating power due to NBI turns off, the thermal quench starts. During thermal quench, the electron density a little bit increases, the electron temperature smoothly decays. The above situation is quite different from that of tokamaks. In typical tokamak discharges, electron temperature does not decay smoothly because some MHD instability and/or destruction of MHD equilibrium happen. In LHD, the toroidal current is mainly induced by beam driven current. After NBI turns off, the toroidal current gradually decreases. As the electron temperature decreases, radiative power increases. When electron temperature becomes sufficiently smaller than about 100eV, the decay time of toroidal current suddenly becomes large, which corresponds to current quench phase. Figure 2 shows the detailed time evolution of toroidal current, its decay time, electron temperature, one turn voltage and threshold of one turn voltage due to avalanche phenomena. In the beginning of the current quench phase, a spike of the current has not been observed, when it is often observed in tokamaks. It is considered that it happens because the destruction of the magnetic surfaces and the toroidal current profile is re-distributed in tokamaks, which does not occur in LHD, it is not observed. In the current decay phase II-2, we observe the extension of the current decay time and the suppression of the one turn voltage, which often happens when the net toroidal current is fairly large. It happens because the joule powers due to self-induced one turn voltage heat the plasma and the electron temperature increases, then the resistivity becomes small. This phenomenon is strongly related with the sustainment of good magnetic surfaces in the current quench phase. Though the sustainment has a possibility to produce runaway electrons, it is not observed in typical LHD discharges because Dreicer voltage is quite large comparing with the observed one turn voltage. Also, one turn voltage has not been maintained for the time to produce the avalanche phenomena though the threshold of the voltage for the avalanche is exceeded.

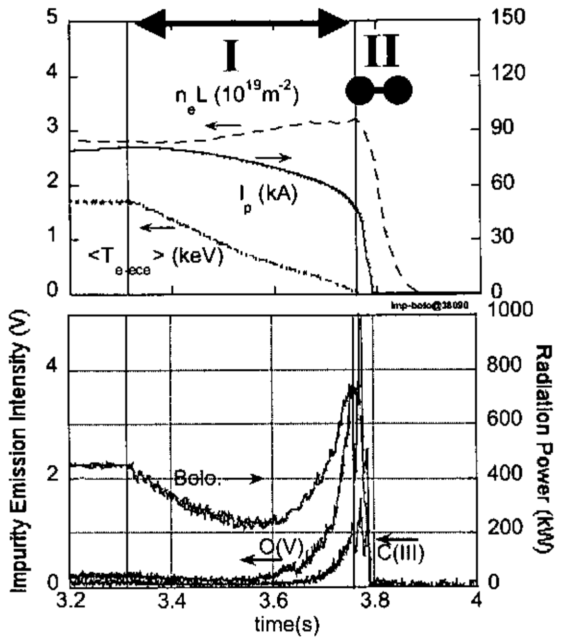

Fig.1. In LHD, typical waveform of toroidal current, density and temperature of electron, and radiation power, spectrum of C(III) and O(V) while the discharge is terminating. Phase I and II denote a thermal and current quench phases, respectively.

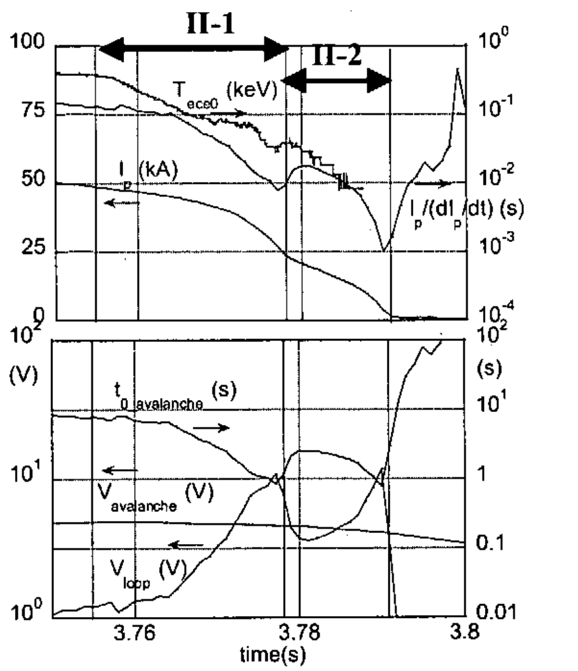

Fig.2. The time-trace of electron temperature, toroidal current, the current decay time, the one turn voltage, and threshold of one turn voltage and time constant of run-away electron due to avalanche.